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# HOW TO DETERMINE THE FERTILIZER REQUIREMENTS OF OHIO SOILS.

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## I: CHEMICAL ANALYSIS NOT A SUFFICIENT GUIDE TO THE FERTILIZING OF THE SOIL.

**Origin of the soils of Ohio:** The larger part of the surface of Ohio has been overrun by the continental glaciers which crept southward from the polar regions in prehistoric times, grinding into gravel and powder the rocks over which they passed and spreading the material thus formed in the sheet of drift clay which covers the northern and western three-fourths of the state, and from which the soils of that region have been formed.

In some places this drift sheet is many feet in thickness; in others but a few feet. In some places the underlying rocks have contributed less to its formation than strata lying to the northward, while in others the glacier, creeping southward for many miles over rocks of similar composition, has left, as it receded to the north, a soil foundation differing but little in composition from that which would have been derived from the decomposition of the rocks lying immediately below. The outcome of this soil history is that throughout the drift covered area of Ohio the soil is stored with the essential mineral elements of fertility in quantities sufficient to maintain crop production at the maximum limit, which the various species of plants are capable of attaining, for a very long time, were they in such form that they could make use of them.

**The soil a great storage battery:** A little reflection, however, will show that if all the plant food in the soil were immediately available it would have been leached out and carried to the sea ages before man came to inhabit the earth, except in those regions where the annual rainfall is less than the yearly evaporation; but as it is, this plant food is stored in such forms that it is only given up little by little, as each succeeding annual growth of vegetation has need of it, and to prevent the possibility of waste, on most soils, and under natural conditions, the quantity thus yielded annually is less than the crops cultivated by man are capable of utilizing, under the favorable conditions for growth which cultivation provides.

**Forms in which plant food is stored:** Some of these forms of food storage may be illustrated by the following examples: Orthoclase feldspar is a constituent of granite, and is one of the chief sources of clays; it is therefore a mineral of great abundance. This feldspar contains nearly 14 percent of potassium, or three times as much as wood ashes, but this potassium is held in such firm combination that feldspar has never yet been made a source of the potash used in human industry, multiple as are the uses of this substance and urgent as is the demand for a cheaper source of it.

Another illustration: Phosphorus is universally distributed through the soil, usually in combination with lime or iron; but when we attempt to use either of these combinations as a fertilizer without some treatment calculated to break up the combination and liberate the phosphorus we get practically no result. Immense beds of phosphate of lime are found in several of the southern states, from which a large part of the phosphorus of manufactured fertilizers is drawn; but so necessary is treatment of this material, either with suitable chemicals or by incorporating it with fermenting manure or other organic matter, that without such treatment it is practically worthless as a fertilizer.

Again: Swamp muck or peat is rich in nitrogen, the air-dry material containing sometimes as much as two percent or more of this element. But this substance is the result of the growth of plants which live where their roots are constantly submerged, and it has acquired such resistance to the ordinary agents of decay that until this resistance is overcome by proper treatment the nitrogen of peat is held in almost as firm a grip as the potassium of feldspar or the phosphorus of the southern rocks.

**Total quantity of plant food not an index to productiveness:** From these examples it is evident that the total quantity of a given chemical element found in a soil is not a trustworthy index to the fertility of that soil. For instance, the East farm of the Ohio Experiment Station, on which some of its soil studies are located, is found to contain 1,100 pounds of phosphorus per acre in the upper foot of soil, or enough of this element for 117 forty-bushel crops of wheat, yet when phosphorus is omitted from the fertilizer this land produces only a little more than 12 bushels of wheat per acre, even when available nitrogen and potassium are furnished in great abundance.

This land also shows in the surface foot a total of 56,000 pounds of potassium per acre, or as much of this element as would be carried in nearly 1,500 forty-bushel crops of wheat; yet the addition of a few pounds of a readily soluble salt of potassium to a fertilizer carrying nitrogen and phosphorus has caused a further increase in the 14-year average yield of wheat of nearly 3 bushels per acre over the yield produced by the nitrogen and phosphorus without the potassium.

Again: This land contains as much nitrogen to the acre as would be found in more than 100 forty-bushel crops of wheat, and yet the addition of 25 pounds of nitrogen per acre, carried in dried blood and nitrate of soda, to a liberal dressing of phosphorus and potassium, has increased the yield by a 14-year average of 6 bushels per acre. But 25 pounds is only about one part in 140,000 of the weight of an acre of soil, taken to the depth of one foot, or seven ten-thousandths of one percent—a quantity so small as to be far within limits of error of ordinary chemical analysis.

**Attempts to determine available plant food:** After discovering that the total quantities of plant food were not a reliable guide to the fertilization of the soil, chemists attempted to discover some method by which the disposition of the soil to give up its stores might be ascertained, and many methods of analysis have been devised in the attempt to imitate the action of the plant roots in unlocking these stores; but here again disappointment has been the reward of the investigator. It is true that some of these methods are, in some respects, a nearer approach to a solution of the problem than the total analysis; but when the chemist faces the fact that an acre of clover will abstract from the soil approximately ten times as much lime and only half as much phosphorus as would a corn crop grown on the same land and under the same conditions, he faces a problem which chemistry is not yet able to solve.

**Studying the soil by pot culture:** Baffled thus in the endeavor to find a short method of determining the needs of a soil through chemical analysis, chemists have attempted the solution of the problem by means of pot cultures, such cultures making it possible to compare a much larger number of different treatments and under conditions of more absolute control with respect to temperature and moisture than is possible in the field; but here again it has been found that, while suggestions of great value may be obtained through this method, it cannot be relied upon as a guide in the practical operations of the farm; for it is impossible to devise a system of pot cultures in which natural conditions, especially with reference to the subsoil, can be reproduced.

**Field experiments the only safe guide:** There is, therefore, no other place in which the problem before us can be solved than in the field itself, and no other method of solution than that of systematic field experimentation. Such field experimentation, however, is a work of far greater difficulty than ordinary chemical analysis. The chemist may take a sample of soil and in a few days' time determine its constituents; but the field experimenter, working on this same soil, must spend years in his work before he can feel that he has the solid ground of positive knowledge under his feet.

**The danger of jumping at conclusions** in field experiment is strikingly illustrated in the 5-year rotation of the Ohio Experiment Station, which has been in progress since 1894. The land selected for this test consisted of portions of a farm which had been used for grain production for many years, with but little manuring or fertilizing. Five tracts of land were selected for this test, each tract or section being permanently laid out in 30 plots of one-tenth acre each. The summer of 1893 was spent in draining the land, and that fall wheat was sown on Section A. Beginning with No. 1, every third plot was left unfertilized, while fertilizing materials of different composition were applied to the plots between. When the wheat was harvested it was found that nearly every plot which had received a fertilizer containing acid phosphate showed a smaller yield of grain than the unfertilized plots between which it lay, whereas when acid phosphate was omitted and muriate of potash was substituted in its place there was an increase in yield. Some of the results are shown below:

TABLE I—Increase or decrease in yield of wheat per acre, first crop in 5-year rotation, 1894.

| Plot No. | Treatment | Increase (+) or decrease (—) per acre |
|---|---|---|
| | | Bus. |
| 2 | Acid phosphate | —2 80 |
| 3 | Muriate of potash | +5.63 |
| 5 | Nitrate of soda | —1 22 |
| 6 | Acid phosphate and nitrate soda | —4.65 |
| 8 | " " " muriate potash | —1.11 |
| 9 | Nitrate soda and muriate potash | +3 53 |
| 11 | Acid phosphate, nitrate soda, muriate potash | —0.42 |
| 12 | " " " " " " | +0.42 |
| 14 | " " " " " " | —1.42 |
| 15 | " " " " " " | —1 25 |
| 17 | Wheat bran and muriate potash | +2.28 |
| 18 | Barnyard manure, 8 tons | —1.53 |
| 20 | " " 4 tons | —0.53 |
| 21 | Acid phosphate, oilmeal, muriate potash | +2.61 |
| 23 | " " dried blood, muriate potash | —0.06 |
| 24 | " " sulphate ammonia, muriate potash | +0 89 |
| 26 | Bone meal, nitrate soda | —3 06 |
| 27 | Superphosphate | —5.36 |
| 29 | Basic slag | —2.08 |
| 30 | Acid phosphate, tankage | —4 58 |

If we had closed our books with this experiment and had contented ourselves with considering the yield of grain only, without reference to the straw, we should have felt justified in assuming that this land needed neither phosphorus nor nitrogen, but only potassium, and that, indeed, the use of materials carrying phosphorus and nitrogen tended to reduce the effect of the potassium. And this view would have been strengthened by the behavior of the clover and timothy following the wheat.

But the fact is that there was a heavier growth of vegetation on the phosphated land, the straw on this land exceeding in weight that on the unfertilized land in practically every instance, and often by large amounts, but the seasonal conditions were such that the earliest ripening wheat failed to fill as well as that ripening later, and as soluble phosphates invariably hasten maturity their application in this case caused a loss in yield of grain, though largely increasing the total yield—a circumstance which has not happened since, in the 14 years of the experiment, as shown by the next table, which gives the increase of wheat on each of the five sections of the test for each year since the work was begun.

TABLE II—Effect of different fertilizing elements on wheat· Increase (or decrease —) in bushels per acre

| Section | Year | Plot and treatment | | | | |
|---|---|---|---|---|---|---|
| | | Plot 2, Acid phosphate | Plot 3 Muriate potash | Plot 6, Acid phosphate and nitrate soda | Plot 9, Muriate potash and nitrate soda | Plot 11, Acid phosphate, mur. potash, nitrate soda |
| A | 1894 | —2 80 | 5 63 | —4 65 | 3 53 | —0 42 |
| | 1899 | 5 92 | 1 91 | 11 23 | 3 00 | 17 19 |
| | 1904 | 12 00 | 3 80 | 15 71 | 3 59 | 17 92 |
| C | 1895 | 4 69 | —1 02 | 7 25 | 0 36 | 7 83 |
| | 1900 | 10 67 | 0 55 | 12 80 | 0 22 | 10 67 |
| | 1905 | 10 70 | —0 14 | 16 77 | 0 91 | 20 37 |
| D | 1896 | 3 10 | 0 74 | 4 10 | 1 31 | 7 76 |
| | 1901 | 17 25 | —0 17 | 20 13 | 0 61 | 21 31 |
| | 1906 | 11 62 | 0 30 | 19 03 | 5 63 | 21 69 |
| E | 1897 | 7 02 | 1 81 | 15 66 | 3 56 | 20 75 |
| | 1902 | 13 06 | 2 86 | 21 91 | 3 11 | 26 97 |
| | 1907 | 9 17 | 1 15 | 15 89 | 3 89 | 16 57 |
| B | 1898 | 3 70 | 1 05 | 11 71 | 2 00 | 17 71 |
| | 1903 | 2 16 | —0 83 | 13 91 | 6 11 | 17 95 |

This table shows that, excepting the crop of 1894, acid phosphate as used on Plot 2 has produced a regular and usually a very large increase in the yield of wheat; that this increase has invariably been augmented when the acid phosphate has been reenforced with nitrate of soda, and that, with but one exception, there has been a further increase in yield when muriate of potash has been added to the dressing of acid phosphate and nitrate of soda.

On the other hand, when muriate of potash has been used alone there have been but two or three instances in which the increase found has been beyond the limits of error, and the combination of this salt with nitrate of soda has been at the very best far from sufficient to pay the cost of the application.

**Cumulative effect of fertilizers:** Considering the table from another point of view, we see that the crops of the first rotation, that is, those harvested from 1894 to 1898, inclusive, have, as a rule, shown a much smaller effect from the fertilizers than those of the subsequent period, this being especially the case with fertilizers containing nitrogen.

**The crop fertilized never uses all the plant food given:** While such extreme variations from the normal, as was shown in the wheat crop of 1894, are unusual, yet a similar experience was encountered while the Station was located at Columbus, and as a rule the results of the first application of fertilizing materials have been less pos tive than those attained on repetition. This is easily understood when we consider that the crop which is directly fertilized never utilizes the whole of the plant food given, but some is always left over for succeeding crops. It is, therefore, impossible to measure the full effect of our treatment by the yield of any single crop.

For example, in the 5-year rotation above mentioned, wheat is followed by clover and timothy, sown together and allowed to stand two years, the first crop being chiefly clover and the second timothy; the land is then planted to corn, which is followed by oats and that by wheat. On one plot in this test, No. 15, the wheat receives a complete fertilizer, containing nitrogen, phosphorus and potassium, but the other four crops of the rotation follow without any further treatment. The effect of this treatment has been to produce the following average increase in total produce per acre for the period of the experiment, the straw or stover being included with the grain:

Increase in pounds per acre:

| Wheat | Clover | Timothy | Corn | Oats |
|---|---|---|---|---|
| 2,291 | 606 | 371 | 743 | 253 |

The total increase in the unfertilized crops amounts to 1,973 pounds, showing that the wheat has utilized but little more than half the effect of the fertilizer.

**Soil investigation a work of years:** From what has been shown above it is evident that to obtain any approximation to a correct knowledge of the needs of a particular soil is a work of far greater magnitude than a few days spent in chemical analysis, or a season given to the comparison of different fertilizing materials in the field; and that, in fact, if the work in the field should end with a single season its results may be absolutely misleading.

There is, in short, no other way of obtaining this knowledge than through field investigations systematically planned and thoroughly executed over a period of years long enough to give a fair average of climatic conditions, which would mean at least ten or twelve years.

**Experiment fields needed in every township:** Many farmers will turn away from this suggestion as being impracticable, and for the great majority it is impracticable. But there ought to be in every county in Ohio, yes, in every township, some farmer or group of farmers of public spirit and scientific habit of thought, who would be willing to devote a few acres of land and a little time and energy to this purpose.

**The Experiment Station has led the way in this work;** it has brought under systematic investigation several typical soils in different sections of the state; it has carried these investigations to such a point that certain general principles which must control such investigations if they are to lead to a successful outcome have been demonstrated; its work is eliminating some of the more difficult features of the problem and enabling us to draw the line between the more abstract questions which can be adequately studied only under the immediate supervision of trained investigators and the simpler problems which may be worked out by the farmer himself, with a little advice and suggestion from the Station. In other words, the Station's extensive field experiments are giving answers of general application to certain fundamental problems, and it is now possible to articulate with these experiments a series of simpler tests, dealing with the more immediately practical side of the question, which would add enormously to the sum of our knowledge concerning Ohio's soils.

**Ohio's crop yields about half what they should be:** The average yield of wheat in Ohio is but 14 bushels per acre. The Experiment Station, on a soil of less than average natural fertility, has obtained 10-year average yields of 25 to 30 bushels, and on better land of 40 bushels per acre. The average yield of corn is about 35 bushels; the Station has made 10-year average yields of 50 to 65 bushels, on soils especially ill-adapted to corn.

These yields are not accidental, but have been repeated so frequently that there is no room to doubt that Ohio's present yields of grain might easily be produced on from two-thirds to three-fourths the area now under cultivation, and at a cost per bushel far below the present cost.

## II: SOME GENERAL PRINCIPLES IN SOIL FERTILIZATION.

While systematic and long continued field investigation is the only method by which the most economical treatment of the soil for fertility maintenance may be accurately determined, yet a few general principles have been established which may aid the farmer materially in the management of his fields.

**The fundamental importance of lime:** Not only is lime one of the essential constituents of every living cell, without which there can be no life, either of plant or animal, but it performs other functions in the soil, the importance of which is scarcely secondary to that of directly feeding the plant. Perhaps the most important of these is that of storing the nitric acid resulting from the work of the nitrifying organisms of the soil. These organisms are living plants, infinitesmally small, whose function is to break up the dead roots and other vegetable matter in the soil and convert their nitrogen into available form, by causing it to unite with the oxygen of the air which penetrates the upper soil spaces, in the form of nitric acid. During summer weather this process goes on continually, the roots of the growing crops absorb the very dilute nitric acid thus formed, and it becomes the source of the nitrogenous bodies found in the stems, foliage and grains of our crops. In these transformations lime appears to serve as a sort of storage battery, combining with the nitric acid and holding it in reserve until the growing roots require it. In the absence of lime this nitric acid will either be washed out of the soil, or, if the rainfall be deficient, it may accumulate to such an extent as to become toxic to the organisms forming it and thus end or interrupt their work.

**Red clover an index to the lime supply:** The fact that common red clover contains several times as much lime as any of the cereal crops would lead us to expect that this crop would be the first to indicate deficiency of lime in the soil, and this is found to be the case. Over the eastern half of Ohio, where sandstones predominate in the surface rocks, it is becoming increasingly difficult to grow this plant. The seed may germinate well in the spring, and there may appear to be a perfect stand of clover, which under favorable weather conditions will persist until harvest. After the wheat is taken off, however, especially if dry weather should supervene, it will be observed that the clover is not growing well. There may be patches of good clover on the moister land, but on the dryer portions it stands still, instead of growing as it should, and if it does not die out entirely before winter sets in it will be found to have disappeared by the following spring, and sorrel will have taken its place.

The liming of such land at once restores the normal growth of clover, provided the lime is properly used; but in applying the lime there are a few important points to be remembered. Among these are the following:

**Lime will not take the place of fertilizers or manure;** on the contrary, lime will only produce its full effect on land that has been previously well fertilized or manured. Lime furnishes only one of the essential elements of plant food; phosphorus and potassium are equally important, as direct plant food, with lime, and the fact that a soil is deficient in lime may be taken as positive evidence that it is also deficient in phosphorus, for the available phosphorus of our soils is probably always the compound known as phosphate of lime. It may therefore be set down as an axiom, to which there is practically no exception in Ohio soils, that if lime is needed phosphorus also is needed, and that neither phosphorus nor lime will perform its full function without the other.

**Not only phosphorus, but potassium also may be needed** before lime can have its full effect, as shown by Table III, which gives the latest results of the experiments reported in Bulletin 159:—

TABLE III—Lime after fertilizers.

| Treatment | 5-year average yield of clover hay per acre |
|---|---|
| None | 1,159 lbs. |
| Lime alone | 1,927 " |
| Lime after acid phosphate | 2,916 " |
| Lime after acid phosphate and muriate of potash | 3,494 " |

**Manure will not take the place of lime:** Manure is usually considered the all-sufficient fertilizer for all soils and all conditions; but manure cannot be substituted for lime, as shown by Table IV, which also reports a continuation of the experiments described in Bulletin 159:—

TABLE IV—Lime after manure.

| Treatment | 5-year average yield of clover hay per acre |
|---|---|
| None | 1,159 lbs. |
| Lime alone | 1,927 " |
| Manure alone | 3,339 " |
| Lime after manure | 4,925 " |

In the case of the manured land the figures given above materially understate the truth, for on this land there was a much ranker growth of timothy during the first season than on the fertilized land, probably in part due to the timothy seeds carried in the manure, so that the larger part of the crop where lime was omitted was timothy, whereas when lime was added, the timothy was hidden by the luxuriant growth of clover.

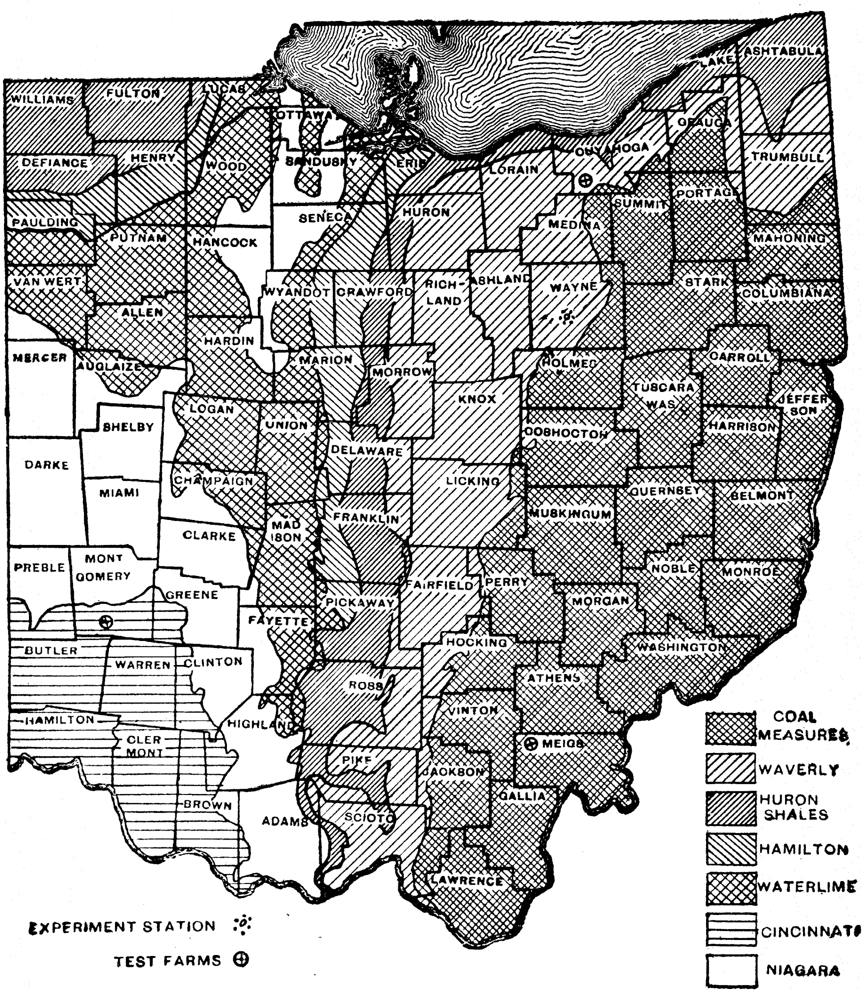
**When to apply lime:** In these experiments neither lime, fertilizer nor manure has been applied directly to the clover crop, which is grown in a 5-year rotation of corn, oats, wheat, clover and timothy. The fertilizers have been distributed over the three cereal crops; the manure has been equally divided between the corn and wheat (8 tons per acre to each crop) while the lime has been applied when the land was being prepared for corn, thus getting it thoroughly mixed through the seed bed in the subsequent cultivations and plowings before the clover seed was sown. This method of application has given better results than when the lime was applied to the wheat land the fall before sowing the clover seed, as would have been expected if the function of lime has been correctly interpreted on page 8. The lime has been used at the rate of one ton of ground, burnt lime per acre. Possibly a ton and a half of hydrated or slacked lime, or two or three tons of ground, raw limestone would accomplish the same result, so far as the clover crop is concerned. For further particulars on liming the reader is referred to Bulletin 159.

**Not all land needs lime:** Reference to the geological map of Ohio, given in this circular, will show that all of the state west of a line drawn approximately from Sandusky to the west line of Scioto county, except a small area in the northwestern corner of the state, is underlaid with limestones. The glaciers have traversed this region in their southward course, as they have that east of this line; but in the one case they have traveled over limestones, grinding them under their feet and reducing them to powder, whereas in the eastern side of the state the underlying rocks have been sandstones. It is therefore to be expected that the soils in the western half of the state will be found to be sufficiently supplied with lime, and this seems generally to be the case. There are occasional old fields throughout this region on which it is becoming increasingly difficult to grow clover, and it is possible that in some cases these older fields need lime, but more often the need here is not lime, but a restoration of the humus which has been worked out of the soil through an exhaustive system of husbandry.

**How to tell whether lime is needed:** Whether it is lime or humus that is needed may easily be determined by dressing a strip across the field with manure and one at right angles to that with lime, the manure, of course, to be plowed under before the lime is applied. This should be done at least a year before sowing the clover seed. If there is a visible improvement in the clover crop on the limed strip, and especially where this strip crosses the manured strip, then it may safely be assumed that liming will pay.

In most field experiments it will not answer to depend upon the eye alone to measure results, for a difference of a few bushels per acre cannot always be detected by the eye; but in the application of lime to clover the more luxuriant growth on the limed land—if lime is needed—is usually such as to leave no room for mistake.

# GEOLOGICAL MAP OF OHIO.



**When the land begins to need lime it is a waste of time, energy and money to continue cultivating it until this need is supplied, for the economical use of every other fertilizing material, including manure, depends upon the lime supply. If that is deficient, everything else must fall short of its possible attainment.**

**Phosphorus next to lime in importance:** While there are large areas in Ohio which do not yet need lime, there is practically not one acre of soil in the state, that has been under cultivation for half a century, that would not pay for the addition of a small quantity of phosphorus. It has been said above that the available phosphorus of the soil is chiefly found in combination with lime, and therefore that where lime is deficient it may at once be taken for granted that phosphorus also is needed. But the converse does not hold true, for the great storehouse of lime in the soil is limestone, which consists chiefly of a combination of lime with carbon and oxygen; a soil may be very hungry for phosphorus, therefore, while still well supplied with lime.

Since their first reclamation from the forest the soils of Ohio have been subjected to two great drains of phosphorus: that of the bones of animals which have grown up and fattened on its pastures and grain crops, and that of the grains which have been sold off the farm to be shipped out of the state or consumed in our rapidly growing cities, which are draining the elements of fertility from our farms as completely as though they were located outside the state.

**The potassium supply:** In the production of grain about three-fourths of the total phosphorus of the plant is found in the grain, while about three-fourths of the potassium remains in the straw. Hence in those systems of agriculture which have for their main object the production of grain the phosphorus supply will be most heavily drawn upon. If the grain is fed to live stock it will still be phosphorus which shows exhaustion first, the phosphorus of the grain being converted into the bones and other tissues of the animal. If the live stock kept be cattle, sheep or horses chiefly, the loss of potassium will be comparatively small, because the hay and straw will be largely consumed on the farm; but if, as in the Miami Valley, the growing and fattening of swine has been the chief industry; a great city has been at the very gates of the farm clamoring for its hay, and a line of paper mills have stood waiting for its straw; and if, in addition to these sources of potash waste large areas have been devoted to the production of tobacco, which from its leafy growth is one of the greatest consumers of potassium, it will be seen that this element, as well as phosphorus, may have become so reduced in the soil as to make it as necessary to look to the supplying of our crops with potassium as with phosphorus.

**Potassium deficient in some soils:** The potassium of the soil which is available for our crops is chiefly held in close combination with clay, and as a rule clay soils are found to be well supplied with this element in their natural condition, but there are two classes of Ohio soils in which potassium is sometimes found to be deficient when they are first brought under cultivation; there are the light, yellow sands constituting the ancient beaches of Lake Erie, and the muck beds found along the watershed between the lake and river drainage. Both soils are deficient in clay, and consequently, however well they might originally have been stored with potassium, it has been largely leached out and carried away. The sandy soils are usually deficient in lime and phosphorus, as well as in potassium; but the mucks are often well supplied with lime and phosphorus, secreted and stored by the shell bearing organisms which have inhabited them. The investigations of the Indiana and Illinois Stations have shown that an application of a potash salt to these muck lands may often be the one thing needed to bring them into profitable production, as shown by Table V, reproduced from Bulletin 93, of the Illinois Experiment Station.

TABLE V—Treatment of drained peaty swamp land by the Illinois Experiment Station.

| Treatment | Yield of corn per acre | |
|---|---|---|
| | Grain bus. | Stover lbs. |
| None | .... | 570 |
| Lime | .... | 590 |
| Lime, nitrogen | .... | 480 |
| Lime, phosphorus | ... | 740 |
| Lime, potassium | 45.4 | 4,150 |
| Lime, nitrogen, phosphorus | .... | 600 |
| Lime, nitrogen, potassium | 58.7 | 4,170 |
| Lime, phosphorus, potassium | 46.9 | 3,860 |
| Lime, nitrogen, phosphorus, potassium | 65 9 | 4,380 |
| Nitrogen, phosphorus, potassium | 58.6 | 3,960 |

The table shows that on this soil there was no production of grain until potassium was added, and that, richly stored with nitrogen as are all such soils, yet the addition of a little available nitrogen increased the effect of the potassium salt, thus showing that the nitrogen of muck or peat is in a form inaccessible to ordinary crops, while lime and phosphorus produced no effect.

Table VI gives the results of 10 years' work by the Ohio Station on a yellow, beach sand, cleared from the forest for the purposes of this test, and cultivated in a 3-year rotation of potatoes, wheat and clover.*

*For further particulars of this experiment, see Bulletin 182, p. 187.

TABLE VI—Effect of fertilizing elements on sandy land.

| Treatment | Increase per acre | |
|---|---|---|
| | Potatoes bus | Wheat bus |
| Phosphorus | 4 38 | 1 27 |
| Phosphorus and potassium | 12 68 | [illegible] |
| Phosphorus, potassium and nitrogen | 21 18 | 5 62 |

It is evident that potassium occupies a relatively important place in the fertilizer for this soil.

**The nitrogen supply.** Given a sufficient supply in the soil of available lime, phosphorus and potassium, there still remains one element which must be provided before maximum production can be attained, namely: nitrogen, an element which, when purchased in commercial fertilizers, outruns all others in cost, but which may be obtained absolutely free of cost by judicious rotation of crops and production and care of manure.

**Clover as a purveyor of nitrogen.** The fact that clover obtains nitrogen from sources inaccessible to the cereal crops, and by its growth enriches the soil in that element, is fully established; but it is to be feared that the ability of clover in this direction is sometimes overrated, and than we expect of it more than it can perform. The following table shows the average yield in Ohio of the crops given for the 10-year period, 1896–1905, together with the quantities of nitrogen, phosphorus and potassium carried in such crop, as computed from average analyses, using the work of this Station in determining the ratio of straw to grain.

TABLE VII—Elements removed per acre by average crops

| Crop | Average yield per acre | Nitrogen | Phosphorus | Potassium |
|---|---|---|---|---|
| Corn | 36 61 bus | 58 2 lbs | 8 70 lbs | 29 00 lbs |
| Oats | 33 64 " | 30 5 " | 5 06 " | 19 38 " |
| Wheat | 13 21 " | 27 3 " | 3 53 " | 9 44 " |
| Clover | 2200 lbs | 45 5 " | 3 67 " | 40 17 " |
| Timothy | 2250 " | 28 3 " | 5 24 " | 16.80 " |

This table shows that the corn crop carries nearly as much nitrogen in the parts which grow above ground as the similar part of the clover crop. It is probable that the clover roots contain more nitrogen than the corn roots, and it is possible that there may be some accumulation of nitrogen in the soil through the action of the root nodules in addition to that found in the roots themselves, but the total amount thus stored, directly and indirectly, by the action of the clover roots, is probably less than that carried away in the hay. In experiments with clover, Berthelot found about two-thirds the total gain of nitrogen in the part above ground and one-third in the roots, whereas in the case of alfalfa the proportions were approximately reversed. (Chimie Vegetale et Agricole, tome I.) It follows, therefore, that where clover is grown in systematic rotation we may reasonably expect it to furnish nitrogen for the crop immediately following, but after that there will usually be a demand for more nitrogen on all soils that have been long in cultivation. This point is illustrated by Table VIII, which gives some of the results attained in an experiment at this Station in the cultivation of potatoes, wheat and clover, the yields given being the average for the first 13 years of the experiment:

TABLE VIII—Effect of nitrogen in potatoes-wheat-clover rotation

| Plot | Treatment | Average yield per acre | |
|---|---|---|---|
| | | Potatoes, 13-year average: bus | Wheat, 12-year average: bus. |
| 8 | Phosphorus and potassium | 197 25 | 35 09 |
| 11 | Phosphorus, potassium and nitrogen | 189.05 | 37 28 |

Large as is the yield of wheat produced by phosphorus and potassium alone in this test, it is still further increased by the addition of nitrogen, although that addition has added nothing to the potato yield. A more thorough study of this test than we have space for here seems to indicate that the soil of Plot 8 is naturally superior to that of Plot 11, and that the superior yield of potatoes on this plot is accounted for in this way, and is not due to any depressing effect of the nitrogen carriers used on Plot 11.

This point is further illustrated by the work of the Pennsylvania State College Experiment Station, in which corn, oats, wheat and clover have been grown in a 4-year rotation since 1882. Table IX shows some of the results attained as an average for the first 20 years:

TABLE IX—Effect of nitrogen in corn-oats-wheat-clover rotation; 20 year average increase per acre.

| Treatment | Average increase per acre | | |
|---|---|---|---|
| | Corn, bus | Oats, bus | Wheat, bus. |
| Phosphorus and potassium ........ ... | 12 86 | 7 57 | 3 93 |
| Phosphorus, potassium and nitrogen. | 12 40 | 8 03 | 7 04 |

In this test the fertilizers have been applied only to the corn and wheat, the oats receiving none, hence a smaller difference is shown in this crop for the application of nitrogen to the preceding crop, as it has been thoroughly demonstrated that whereas the usual carriers of phosphorus and potassium are not readily washed from the soil, the nitrogen carriers, especially nitrate of soda, cannot be counted on for more than a single season after application. The wheat crop in this test is evidently ready for more nitrogen.

In both experiments above quoted the clover crop has been immediately followed by a cultivated crop—potatoes or corn—and such crops have the advantage of growing during the warm months, when the processes by which the organic nitrogen of the soil is converted into available form are most active, and hence the corn and potatoes have had the advantage of this source of nitrogen, in addition to that furnished by the clover. In the Ohio station's 5-year rotation the corn has grown on timothy sod, instead of clover sod, the timothy having followed an imperfect yield of clover, owing to lack of lime in the soil, with the following result:

TABLE X—Effect of nitrogen in rotation of clover, timothy, corn, oats and wheat at Wooster. 13 years' average results.

| Treatment | Average yield per acre | | | |
|---|---|---|---|---|
| | Timothy, lbs. | Corn, bus. | Oats, bus. | Wheat, bus. |
| Phosphorus and potassium ........ | 2,935 | 41.07 | 40 00 | 18 94 |
| Phosphorus, potassium and nitrogen. | 3,395 | 47.50 | 50 86 | 26.00 |
| Percentage increase for nitrogen...... | 11 6 | 11.6 | 27 1 | 37 3 |

Even the timothy crop here, though immediately following clover, is ready for more nitrogen. The corn crop, growing under more favorable conditions for nitrification, shows no greater increase from the application of additional nitrogen than the timothy, but with the oats and wheat the response to fertilizer nitrogen steadily increases with the distance from the clover crop.

The same 5-year rotation has been repeated at the Strongsville test farm, but in this case not only has the clover crop been poor for lack of lime but the timothy crop has so often completely failed that it is only possible to give a 5-year average for this crop. The general results are as shown in Table XI:

TABLE XI—Effect of nitrogen in rotation of clover, timothy, corn, oats and wheat at Strongsville test farm. 12 years' average results.

| Treatment | Average yield per acre | | | |
|---|---|---|---|---|
| | Timothy, lbs. | Corn, bus. | Oats, bus. | Wheat, bus. |
| Phosphorus and potassium... ....... | 2054 | 35 31 | 44.35 | 14 72 |
| Phosphorus, potassium and nitrogen. | 2416 | 38.18 | 50 72 | 17.62 |
| Percentage increase for nitrogen..... | 7 9 | 10.8 | 14 4 | 19.7 |

These results all point to one conclusion, namely: that a luxuriant clover crop which has been mown for hay may leave behind it in the soil a sufficient surplus of available nitrogen to supply the needs of the first crop immediately following, but the second crop following will need a fresh supply of nitrogen, and this need will increase with every subsequent crop; while if the clover crop has been defective the crop grown on its sod will be ready for more nitrogen. It is evident, therefore, that the nitrogen supply cannot be maintained by the growing of a crop of clover once in five or six years, nor even once in three years, if the clover be made into hay.

If the clover be turned under, thus giving the entire crop to the maintenance of fertility, a different result may be expected. Just what would be the outcome of this method we have as yet no data for determining, other than the analysis of the plant and the general results of field investigations. These results, however, have shown that there would in all probability be such waste of the nitrogen provided by the clover that a sufficient supply for the second crop following would be the most that could be expected, and even that would be problematical.

**The effect of nitrogen is of short duration:** In the Rothamsted experiments barley was manured every year for the 20 years, 1852–1871. The manuring was then discontinued on half the land, with the result that in 1872 the yield on the unmanured half was 94 percent of that on the land which was still manured, while in 1873 it fell to 79 percent and in 1874 to 71 percent. But the nitrogen carried in this 20 years' manuring should have left a far greater store in the soil than that to be obtained from turning under a single crop of clover.

In the experiments of the Ohio station yard manure has been applied directly to wheat in one test, and to corn, followed by wheat, in another, the manure being used at the rate of 8 tons per acre in both tests. The result has been that the manure applied directly to the wheat has produced an average increase of 12.54 bushels per acre for the 10 years, 1898 to 1907, whereas that left over by the corn has increased the wheat by 8.48 bushels for the same period. The general average yield of the unfertilized land for the period under consideration was 10.41 bushels in one case and 10.43 bushels in the other.

The general outcome of all investigations of this character is that, whereas we may expect the soil to take care of and store away for future use very considerable quantities of phosphorus and potassium, yet it has no corresponding capacity for storing nitrogen. That must be utilized as fast as it becomes available or it is lost.

**Clover must be reenforced:** In order for clover to perform its full function as a green manure it must be reenforced with some carrier of phosphorus. The analysis of the clover plant shows that it is relatively low in this element, as would be expected from the small proportion which its seed bears to the total weight of plant. An acre-yield of clover hay contains only half as much phosphorus as an equivalent yield of corn, and if two or three cereal crops are to follow the green manuring with clover it will be necessary to furnish them practically their full requirement of phosphorus.

There may be exceptional circumstances when the giving of one season out of three or four to the growing of a manure crop may be justifiable; but under ordinary conditions it will be found more profitable to convert the clover into animal products and return the resultant manure to the soil.

**Clover and manure the cheapest sources of nitrogen:** Next to clover, the cheapest source of nitrogen to the farmer is animal manure. On the great majority of the farms of Ohio it is possible to produce manure without cost, the growth of the animal or the milk or wool produced paying for the feed and care. This question is more fully discussed in Bulletin 183 of this Station.

## CONCLUSIONS.

From what has been said above the following conclusions may be drawn, as applicable in general to Ohio soils:

**Lime:** As a rule, lime is needed only in the eastern half of the state, although there may be old fields in the western half from which the surface lime has been leached and which would now be benefited by liming. The best method of determining this point is to lime a strip through a field which is being prepared for corn and note the effect—not on the corn crop, but on the clover which should follow the corn a year or two later.

**Where lime is needed it is of fundamental importance that it be supplied. Neither manure nor fertilizers will take its place, nor will they perform their full functions in the absence of sufficient lime.**

**Phosphorus;** On practically all Ohio soils that have been for any length of time in cultivation—possibly excepting the mucks—phosphorus must be supplied before the maximum yield of any crop can be attained. The longer the land has been in cultivation the greater the need of phosphorus, but many comparatively new soils will respond to it, especially if they have previously been pastured.

**If the supply of available phosphorus in the soil is deficient neither clover nor manure will produce their full effect. The maintenance of this supply therefore lies at the very foundation of successful agriculture.**

**Potassium** will usually give a further increase of crop after phosphorus has been furnished. It is especially indicated for regions where hay and straw have been sold off the farm, or where tobacco has been grown, because this element is found chiefly in the leafy portions of the plant. Except possibly on muck soils, *potassium should always be used in connection with phosphorus;* otherwise a large part of its effect will be lost.

**But lime, phosphorus and potassium will not maintain the fertility of the soil,** however abundant their supply may be. The tables given on the preceding pages show that the maximum yield of crop is never attained until nitrogen is supplied, either by the growing of clover, the application of manure, or of nitrogenous fertilizers. When nitrogen is purchased in the fertilizer sack, however, as has been already stated, its cost outruns the combined cost of all the other elements of fertility combined. It is therefore either the cheapest or the costliest element of fertility, according to the system of management followed.

## PRACTICAL APPLICATIONS.

From what has been shown above it is safe to assume that any tract of land in Ohio which has been for any considerable time in cultivation will respond to fertilizers carrying phosphorus.

If the system of agriculture has been one in which hay and straw have been sold off the land for any considerable period, then it is reasonably certain that potassium is also needed in the fertilizer.

If it has been more than a year since the land was occupied with clover, or since it was dressed with manure, then nitrogen is needed in addition to phosphorus and potassium.

These rules apply to all soils except the mucks, and to all crops. It is true that crops grown chiefly for the seed consume relatively more phosphorus than those grown principally for the foliage, and that the latter consume relatively more potassium than the former; but phosphorus and potassium are comparatively stable in the soil, and in a properly adjusted rotation the fertilization will be so planned as to provide for the needs of both classes of plants.

**Without the production of clover or similar crops, as part of a systematic rotation, economic farm management is impossible in Ohio:** every energy should therefore be bent to the securing of the highest thrift of the clover crop, and as a first step to this end the lime supply should be made sure of. But clover must have phosphorus and potassium, as well as lime, and hence the plan of management should be such that these necessary elements will be regularly provided.

The production of clover leads logically to the keeping of live stock, and the keeping of live stock means the production and careful use of manure. If a considerable part of the live stock kept consist of cattle, sheep or horses, the hay and bedding consumed will return to the land the larger part of the potassium carried away in the crops; but whatever the system of agriculture, unless it be limited to the production of butter or wool, there will be a constant drain of phosphorus from the farm which can only be met by the purchase and return of this element, either in phosphatic feeds, such as wheat bran, or in phosphatic fertilizers.

The experiments reported in Bulletin 183 of this Station have shown that it is possible to maintain crop yields in Ohio at a level nearly twice as high as the average yields of the state, on lands much poorer than the general average, by the use of fresh stable manure, reenforced with phosphatic materials. These experiments have also shown that, by combining clover growing with manure production, and reenforcing the manure with phosphorus, the produce of the land will be sufficient to maintain and steadily increase its fertility, and that the income from the production of meat may be at least as great as from the sale of the feeds required to produce it, thus giving the gains from increased productiveness as clear profit.

**Most Ohio farms do not carry enough live stock** to produce the manure necessary for the production of maximum crops, and for such farms the following suggestions are offered, these suggestions being drawn from the Station's investigations, and from the practice of the most successful farmers of the state.

**Manure the corn crop.** Get all the manure possible onto the land ntended for corn, taking it wherever practicable directly from the stable to the field and spreading at once. Farmers who follow this ipractice state that manure spread in the fall produces more corn than that spead in the spring. There is far less loss from spreading manure on the snow than from letting it leach in the barnyard.

**Phosphate and manure:** If the manure has not been mixed with acid phosphate, steamed bone meal or floats during its accumulation, it may safely be taken for granted that the corn which has been manured will respond to a moderate application, 150 to 200 lbs. per acre, of acid phosphate, applied to the entire surface after the land has been prepared for the crop.

**Do not fertilize in the hill,** because the corn (or potatoes) will consume but little more than half the fertilizer; the next crop will be oats or wheat, and a little streak of fertilized land every 3 or 4 feet will do these crops but little good. Moreover, the corn itself will not get the full benefit from the fertilizer if applied in the drill, because its roots will be induced to follow the drill rows instead of foraging throughout the entire seed beed—and the same applies to potatoes.

**The oats crop** which usually follows corn in northern Ohio will respond on the thinner soils to a complete fertilizer, low in nitrogen but high in phosphorus, such as would be made by mixing 200 pounds of muriate of potash with a ton of steamed bone meal and using at the rate of 200 pounds per acre, or by mixing the following formula:

| Carriers | | Fertilizing constituents | | |
|---|---|---|---|---|
| | | Nitrogen Lbs. | Phosphoric acid Lbs. | Potash Lbs. |
| Nitrate of soda, | 25 lbs. | 4.0 | ... | .... |
| Acid phosphate, | 155 " | .... | 21.7 | .... |
| Muriate of potash, | 20 " | .... | .... | 10 |
| Total | 200 " | 4 0 | 21.7 | 10 |
| Percentage composition | | 2.0 | 10.8 | 5 |

Purchasing nitrate of soda at 3 cents per pound and muriate of potash at 2 cents in New York, in lots of a single sackful, with half a cent per pound added for freight, and acid phosphate at $16 per ton, the above formula would cost about $27 per ton on the farm. Its cost would be materially reduced by purchasing in larger quantities.

On black lands or clays which have been kept in such condition by liberal manuring that there is danger of the oats lodging, the nitrate of soda may sometimes be reduced, and the other constituents increased, to advantage.

**The wheat crop** following the oats will pay for a larger dressing of nitrogen, both because it is farther removed from manure or clover and because it is a crop of higher acre-value than oats. For such a crop, occupying this point in the rotation—that is, two years or more after clover or manure, the following formula is recommended:

| Carriers | | Fertilizing constituents | | |
|---|---|---|---|---|
| | | Nitrogen Lbs. | Phosphoric acid Lbs. | Potash Lbs. |
| Steamed bone meal, | 100 lbs. | 2 | 24 | . . |
| Acid phosphate, | 130 " | ... | 18 | ... |
| Muriate of potash | 20 " | .... | .... | 10 |
| Nitrate of soda | 50 " | 8 | .... | .... |
| Total | 300 lbs. | 10 | 42 | 10 |
| Percentage composition | | 3⅓ | 14 | 3⅓ |

The nitrate of soda not to be mixed with the other materials, but held until spring and then sown broadcast over the wheat in April after growth has well started.

The bone meal in this formula will furnish a small supply of nitrogen which will assist the wheat in establishing its root hold in the fall. The acid phosphate acts more promptly than the bone meal, and thus stimulates fall growth and hastens maturity at harvest. The nitrate of soda, applied in April, will usually abundantly pay for itself, providing phosphatic fertilizers have been used in the fall preceding. If the nitrate be mixed with the fertilizer and used in the fall its effect is liable to be lost before spring growth begins. It is a coarse salt and very easily sown broadcast.

**The clover crop:** Such an application as that just described will make an excellent foundation for the clover crop, provided the lime supply is naturally sufficient or has been provided for. If more potassium has been given than the oats or wheat needed, it will not waste, but will be held in the soil until the clover calls for it, the behavior of potassium and phosphorus being very different from that of nitrogen in this respect.

The above suggestions are of general application for clays or sandy soils which have been long in cultivation. For black lands it is possible that less nitrogen may be required; but there can be little doubt that the wheat crop at least on these soils may be greatly benefited by the use of acid phosphate. Had this material no other property than that of hastening maturity its use on such soils would be indicated, for a few days' difference in date of ripening sometimes means a great deal for the wheat crop; but corn is the most extravagant of our crops in its consumption of phosphorus, and the black lands of northwestern Ohio which have been devoted so largely to corn growing must soon begin to show deficiency in available phosphorus, if they do not already do so.

## FERTILIZING MATERIALS.

The following are a few of the principal fertilizing materials available to the farmers of Ohio:

**Nitrate of soda:** This is the most effective carrier of nitrogen in use for fertilizing purposes. It comes from Chili, South America, and hence is sometimes called "Chili saltpeter". The commercial article should contain about 15¾ percent nitrogen.

**Sulphate of ammonia:** This is a by-product from the manufacture of illuminating gas. It is a brownish salt and should contain a little over 21 percent of nitrogen.

**Tankage:** This is a product of the slaughter houses. In its manufacture scraps of meat, tendon, etc. are thrown into vats and their grease cooked out, after which the residue is dried and ground into a meal. It is variable in composition, containing from 6 to 10 percent of ammonia and from 10 to 25 percent of "bone phosphate", bone phosphate being that compound of phosphorus and lime found in bones, and which contains about 46 percent phosphoric acid and 54 percent lime. A 6-25 tankage would contain 6 percent "ammonia" and 25 percent "bone phosphate", or nearly 5 percent nitrogen and about 11 percent phosphoric acid.

Tankage is slower in action than nitrate of soda or sulphate of ammonia, and for this reason is better suited to fall sown crops, whereas the other carriers are more valuable for spring crops.

**Acid phosphate** is the standard carrier of phosphorus. It is usually sold to contain 14 percent "phosphoric acid", equivalent to a little more than 6 percent phosphorus. It is made by mixing the finely ground, phosphatic rock, found in Tennessee and other southern states, with approximately an equal weight of sulphuric acid, this treatment being essential to make available the otherwise insoluble rock phosphate.

**Steamed bone meal** is an excellent source of phosphorus, being preferable to raw bone meal because the cooking has made its phosphorus more available. It usually contains one to two percent nitrogen, with about 25 percent phosphoric acid. After making allowance for its nitrogen, the pound of phosphorus in steamed bone meal usually costs no more than that in acid phosphate.

**Basic slag,** sometimes called "Thomas slag" or "odorless phosphate" is an effective carrier of phosphorus. Like steamed bone meal it contains no sulphuric acid, and therefore is better suited to acid soils than acid phosphate.

**Muriate of potash** is the chief source of fertilizer potash. It is a salt, mined in Germany, and comes to this country in sealed bags, usually containg about 224 pounds, and sold to contain 50 percent actual potash.

**Sulphate of potash** is also sold for fertilizing purposes, but in this form the actual potash usually costs about a cent a pound more than in the muriate.

**Kainit** is a crude potash salt, containing a mixture of muriate of potash and common salt, the actual potash running in the neighborhood of 12 to 13 percent. Because of the large amount of useless material on which freight must be paid the pound of potash usually costs more in kainit than in the muriate, notwithstanding the fact that a ton of muriate costs several times as much as one of kainit.

Acid phosphate, steamed bone meal and tankage may be purchased in the local fertilizer markets or at the Union Stock Yards, Chicago; but nitrate of soda and muriate of potash can be purchased to better advantage in New York or Baltimore, since the entire supply of these materials is imported from South America and Europe.

The general agencies for these materials are William S. Myers, 12 to 16 John St., New York City, for nitrate of soda, and The German Kali Works, 93 to 99 Nassau St., New York City, for potash salts.

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